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Validation of a haptic virtual reality simulation in the context of industrial maintenance

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Abstract. This paper presents a VR simulator enhanced with haptic force feedback, that enables training on the performance of fine grinding and polishing tasks and some of the results from an experimental study conducted during the demonstration phase within the ManuVAR project.

Keywords: Haptics, Virtual Reality, training simulator, motor skills training.

1. Introduction

In order to prevent failure in manufacturing processes, industrial plants conduct maintenance campaigns during which engineering services companies as Tecnatom S.A. are required for the inspection of operating components.

The Metallographic replica is a non destructive inspection technique that requires prior fine grinding and polishing operations to remove oxide scale from material surfaces [1]. The performance of those tasks requires advanced skills in angling and pressuring power tools on the surface of the material. However, training unskilled workers is troublesome in the extent that supervisors cannot provide accurate feedback on the on-going performance and movements characteristics.

Virtual Reality (VR) enhanced with haptic force feedback (FF) would enable training complex mechanical tasks and thereby supplements conventional training. It has been demonstrated that VR training enhanced with FF and augmented feedback (AF) enables learning force skills required in mechanical operations [2]. However, no study has reported the effectiveness of VR training to acquire tool inclination skills.

In this paper, we present and assess a VR training system enhanced with FF and AF for fine grinding and polishing tasks.

2. Description of the VR system

The VR training system consists of a simulator that enables practicing fine grinding and polishing tasks in a virtual environment (VE). A haptic device was used to simulate the functioning of a portable flexi-drive tool (vibrations and tangential forces) and interact within the VE. The training simulator provides the VE which consisted in a 3.0× ~4.5 cm area located on the lateral of a pipe in a factory floor.

The training was enhanced with AF in the form of a colour map that used a colour scale (from red to green) to indicate in real time the completion of the task in the metallographic replica area. The colour map was overlaid on the metallographic replica area and magnified in a right lateral window. The colour map consisted of a texture of 64×64 pixels which were identified as elements of a matrix $A_{64\times64}(t)$. Each element of $A(t)$ stored the time of correct performance of the task on the corresponding pixel as in *Eq. 1*.

Correct performance for the fine grinding task consisted in generating scratches by flattening the rotating wheel on the material surface and maintaining applied angle and force within ranges of correctness respectively set to 75º to 90º and 1N to 5N. These thresholds defined a segment area S_+ on the flattened rotating wheel in which produced scratches had the desired direction. Outside these thresholds, the area S_- is defined. The flattened rotating wheel generated scratches with inappropriate direction.

Correct performance for the polishing task consisted in flattening the rotating wheel by maintaining applied angle and force within ranges of correctness respectively set to 0º to 20º and 1N to 5N. These thresholds defined a segment area S_+ on the rotating wheel, considered as the optimal flattening on the material surface. In the case of the polishing task, there was no area S_-.

$$\left.\begin{array}{l}\forall\, i \in [1,64]\\ \forall\, j \in [1,64]\end{array}\right\} \Rightarrow a_{i,j}(t) = a_{i,j}(t-1) + b_{[i,j]}(\mathrm{t}) \qquad \textit{Eq. 1}$$

Where $b(t)$ was thus expressed as below (*Eq. 2*):

$$b_{[i,j]}(\mathrm{t}) = \begin{cases} 0 \Leftrightarrow \begin{cases}[a_{i,j}]_{m\times n}(t) \notin S_+\\ [a_{i,j}]_{m\times n}(t) \notin S_-\end{cases} \\ \Delta T \Leftrightarrow [a_{i,j}]_{m\times n}(t) \in S_+ \\ -\Delta T \Leftrightarrow [a_{i,j}]_{m\times n}(t) \in S_- \end{cases} \qquad \textit{Eq. 2}$$

Where ΔT is the elapsed time between two graphical frames.

3. Validation of the VR system

An experiment was conducted during the demonstration phase of the EU funded project ManuVAR [3], to (1) evaluate the effectiveness of the VR system for training on fine grinding and polishing tasks and (2) study the external validity of the system.

Six trainees (1 female and 5 males) aged from 30 to 55 and two experts (2 males) aged 31 and 35 took part in our experiment. All participants were workers in Tecnatom S.A. One trainee stated to be skilled in performing the metallographic replica technique, other four had little knowledge and another was completely novice. Participants reported no physical disabilities but one trainee was colour-blind.

All participants received a prior part task training of angle and force skills in VR.

The VR system ran on the ManuVAR platform distributed on two workstations. PC 1 supported the ManuVAR components that managed the platform and a haptic server [1]. A Phantom Desktop, able to render a maximum force of 7.9 N on 3 DOF, enabled interacting within the VE. PC 2 displayed the simulator on a 3D screen (W: 1.5 × H: 1.2 m) with a resolution of 1280 × 960 pixels. The 3DVia Virtools VR player rendered the VE at 60Hz refresh rate. The VE was visualized through passive stereoscopic glasses tracked by 6 infrared cameras from Natural Point Optitrack. A separate laptop located in an adjoining room was used to display the instructions.

The experiment procedure consisted of a within-subject design involving experts during the first day, and trainees during the two next days. Trainees were randomly distributed in two groups: One trained on fine grinding (FG) and the other on polishing (POL).Before starting, participants received instructions about the task objective and were explained how to interpret the augmented feedback. Participants stood at about 1 m in front of the screen. The haptic device was placed in front of them and elevated so the haptic workspace physically matched with the manipulation workspace in the VE. Participants handled the haptic device as a real portable tool.

Trainees performed a pre-evaluation step composed of two items of 3 minutes: (1) a familiarization item during which they were asked to perform the task they were assigned being assisted by the colour map; (2) an evaluation item during which they performed the task with no visual aid. Then, trainees practiced the task during two items of 3 minutes with the colour map being displayed on demand. Finally, trainees were evaluated while performing the task during 3 minutes with no colour map. Experts went through the training procedure described for trainees for both tasks.

4. Results

The average completion rate of the task reported on the colour map was measured for each participant during the pre and post-evaluation steps in order to be compared.
All participants from FG (Figure 1.a) and two participants from POL improved their performance after training (Figure 1.b**¡Error! No se encuentra el origen de la referencia.**), although one of them was colour-blind. However, for one participant, training resulted in a negative effect probably due to poor visual cues dominating haptic cues for contact information. Thus, enhanced visual cues may improve this aspect.

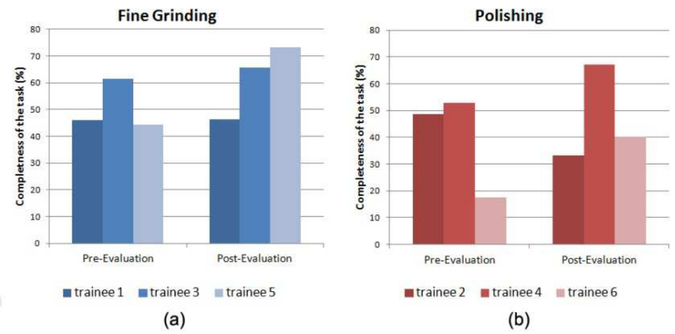

Figure 1. Completion of (a) fine grinding and (b) polishing tasks before and after training.

The difference in the performance of fine grinding (Figure 2.a) and polishing (Figure 2.b) tasks between experts and trainees during the pre-evaluation step validates the system as a good representation of the real world task.

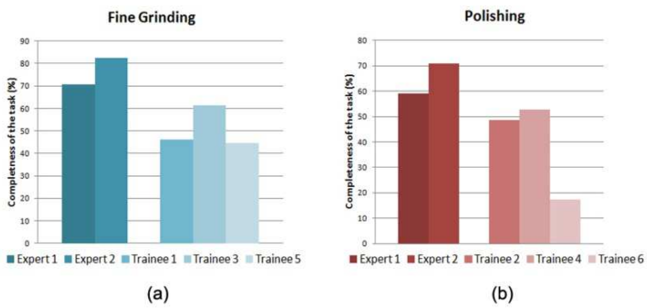

Figure 2. Experts performed (a) fine grinding and (b) polishing tasks better than trainees.

5. Conclusion

This study reported the effectiveness of a VR training system to improve the performance of mechanical tasks simulated in a VE. Moreover, performance measures enabled differentiating levels of expertise. Thus, external validity for the simulator was found. In the future, we will adapt the colour map to colour-blindness.

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